JÜLICH
FORSCHUNGSZENTRUM

Life Cycle Sustainability Assessment of rare earth permanent magnets

22.09.2016

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Agenda

Introduction

System description

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Results single assessments

Approach multi-criteria decision-making

Results multi-criteria decision-making

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Introduction

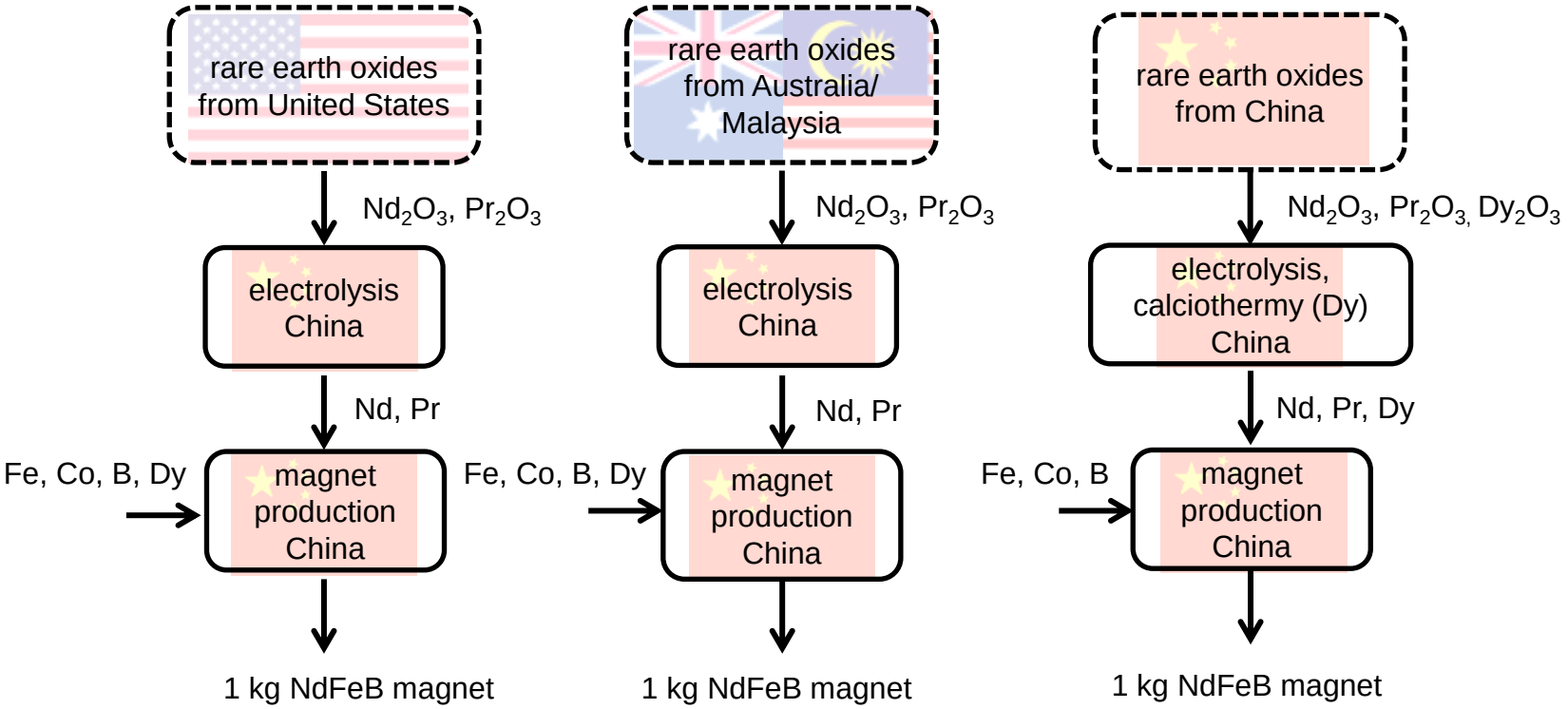
- Rare earth (RE) magnets are part of wind power plants (increase of renew-ables → higher demand)
- RE are considered as critical resource
- Known environmental problems during production

Source: Siemens

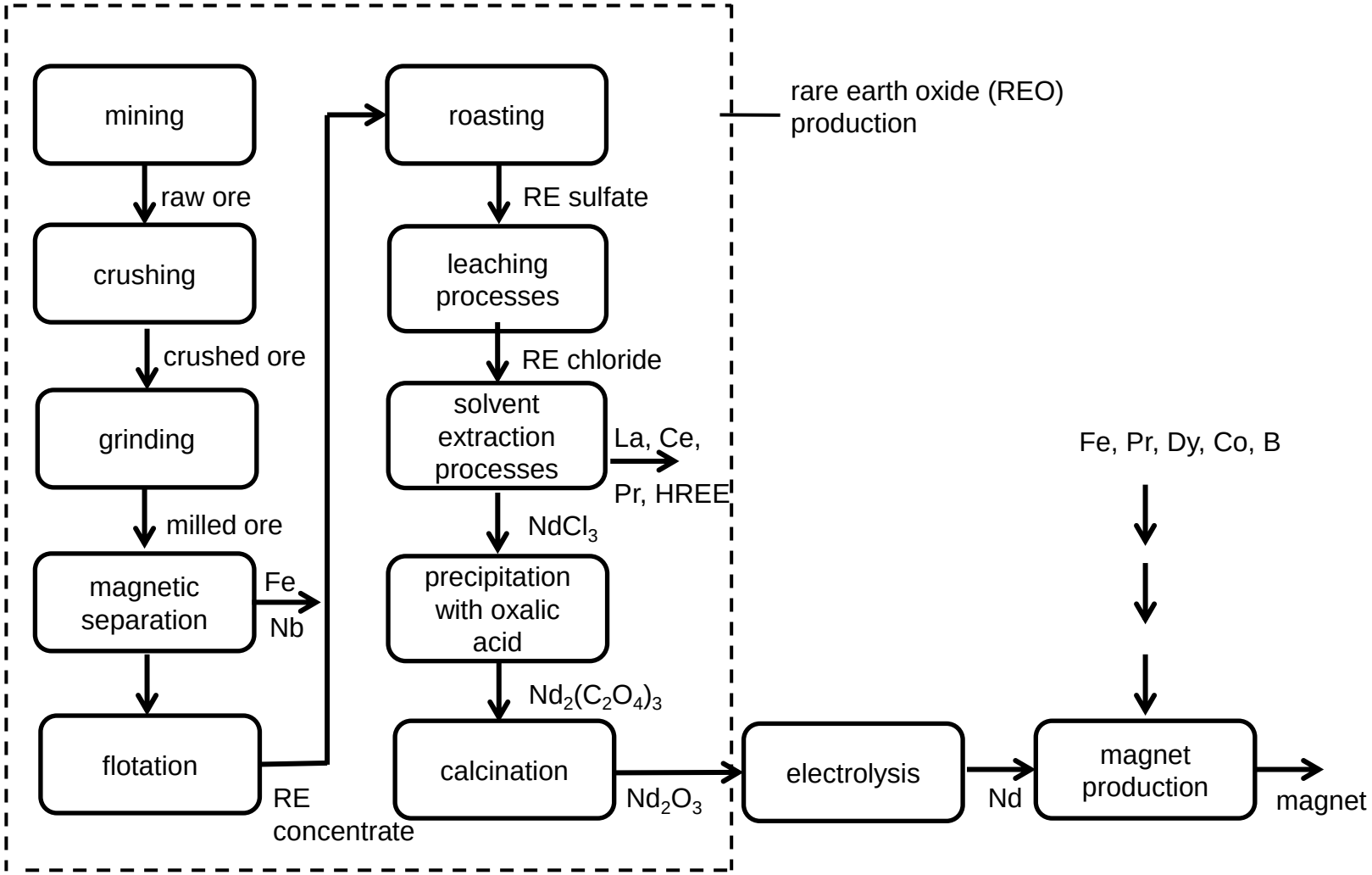
Comparison of Chinese process chain with two western process chains (Australia/Malaysia; U.S.) within a 4-years project with Aachen University and Siemens AG

Source: Siemens

System description



System description example China, Nd



Life Cycle Assessment

Ecoinvent 2.2 + Gabi

ReCiPe 1.08 midpoint (H)

- Fossil Fuel Depletion
- Climate Change
- Terrestrial Acidification
- Freshwater Eutrophication
- Ozone Depletion
- Photochemical Oxidant Formation
- Human Toxicity
- Terrestrial Ecotoxicity
- Freshwater Ecotoxicity
- Ionizing Radiation
- Particulate Matter Formation

Life Cycle Costing

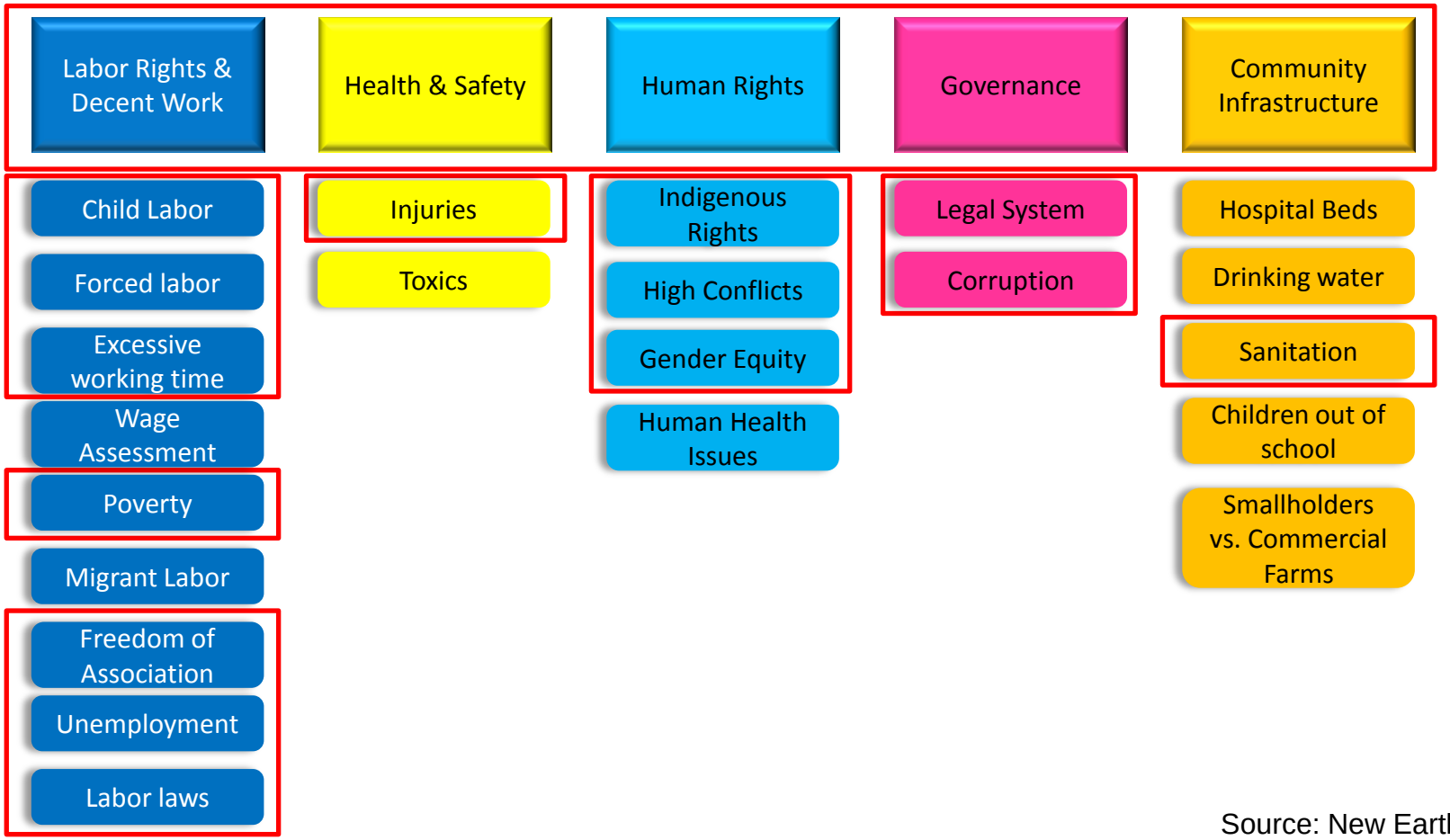
- Top down approach
- Basis: published CAPEX and OPEX of REOs
- Own calculations (Siemens AG) of CAPEX and OPEX for metal and magnet production

Supply Chain	CAPEX Mio. US	OPEX US$/kg REO
Australia	1125	10.11
U.S.	895	27.70
China	595	5.58

- Sum of CAPEX and OPEX results in Total Cost of Ownership (US$/kg magnet)

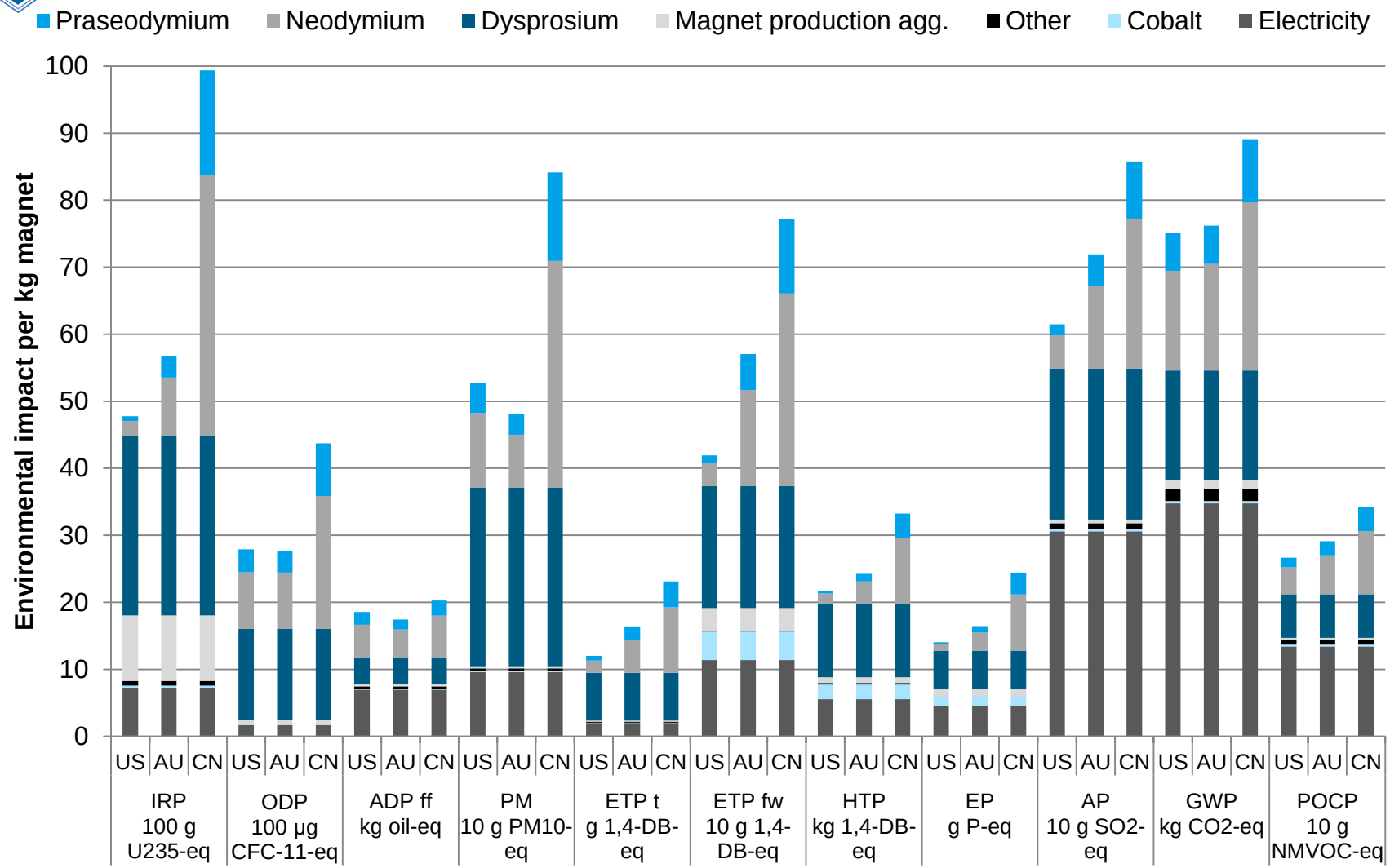
Social Life Cycle Assessment

Social hotspots database

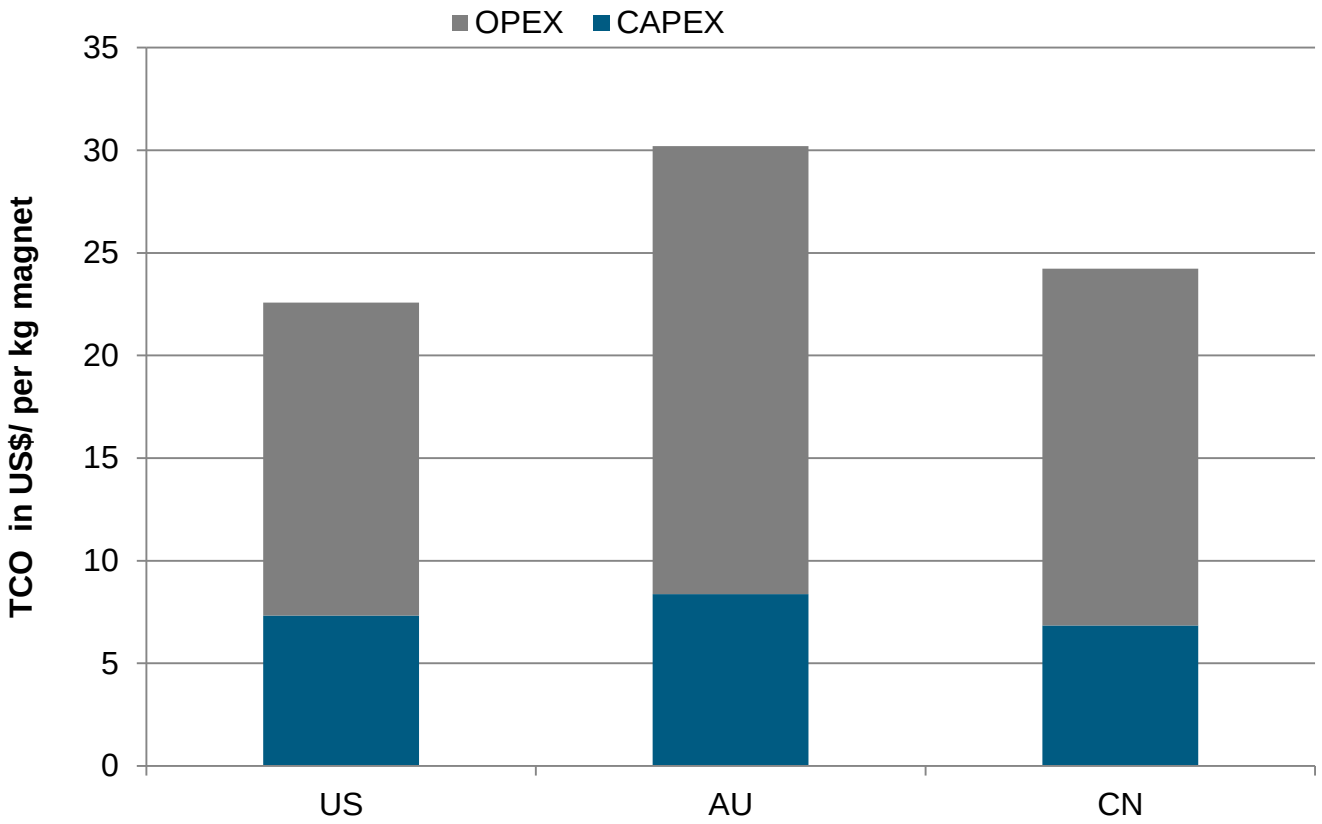


Source: New Earth

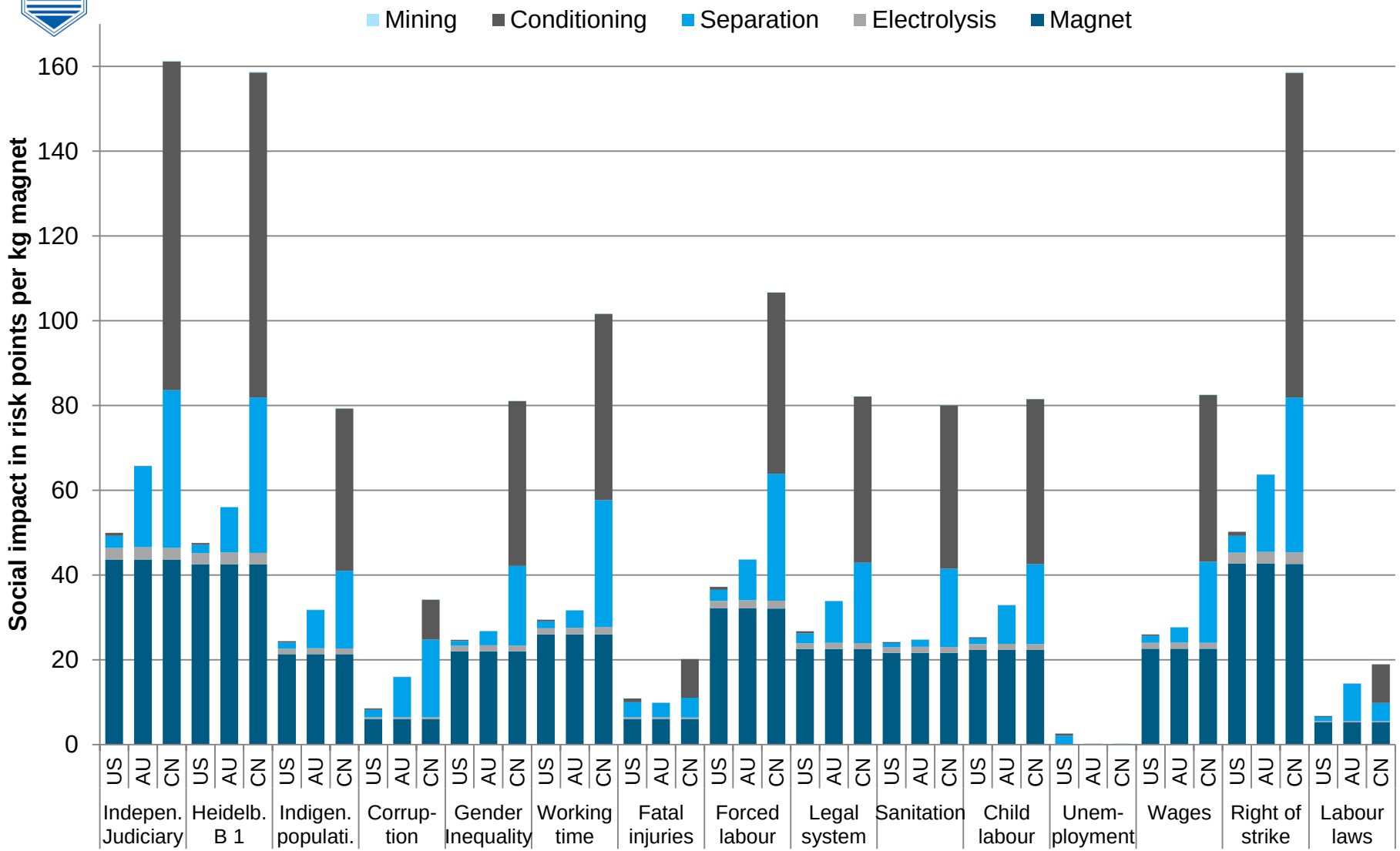
Results LCA


Praseodymium
Neodymium
Dysprosium
Magnet production agg.
Other
Cobalt
Electricity
Environmental impact per kg magnet
100
90
80
70
60
50
40
30
20
10
0
US AU CN
IRP 100 g U235-eq
ODP 100 µg CFC-11-eq
ADP ff kg oil-eq
PM 10 g PM10-eq
ETP t g 1,4-DB-eq
ETP fw 10 g 1,4-DB-eq
HTP kg 1,4-DB-eq
EP g P-eq
AP 10 g SO2-eq
GWP kg CO2-eq
POCP 10 g NMVOC-eq

Results LCC



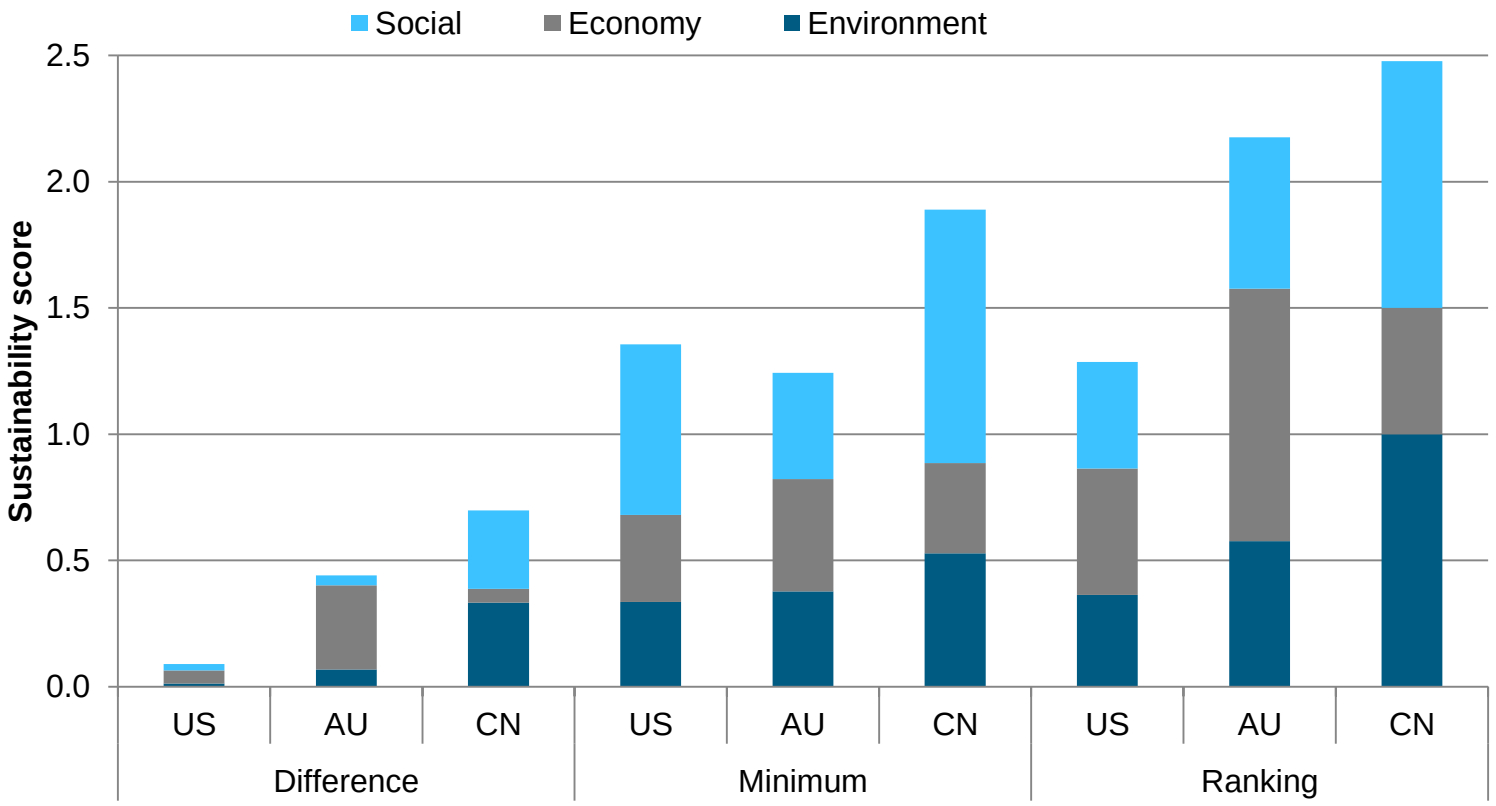
Results s-LCA



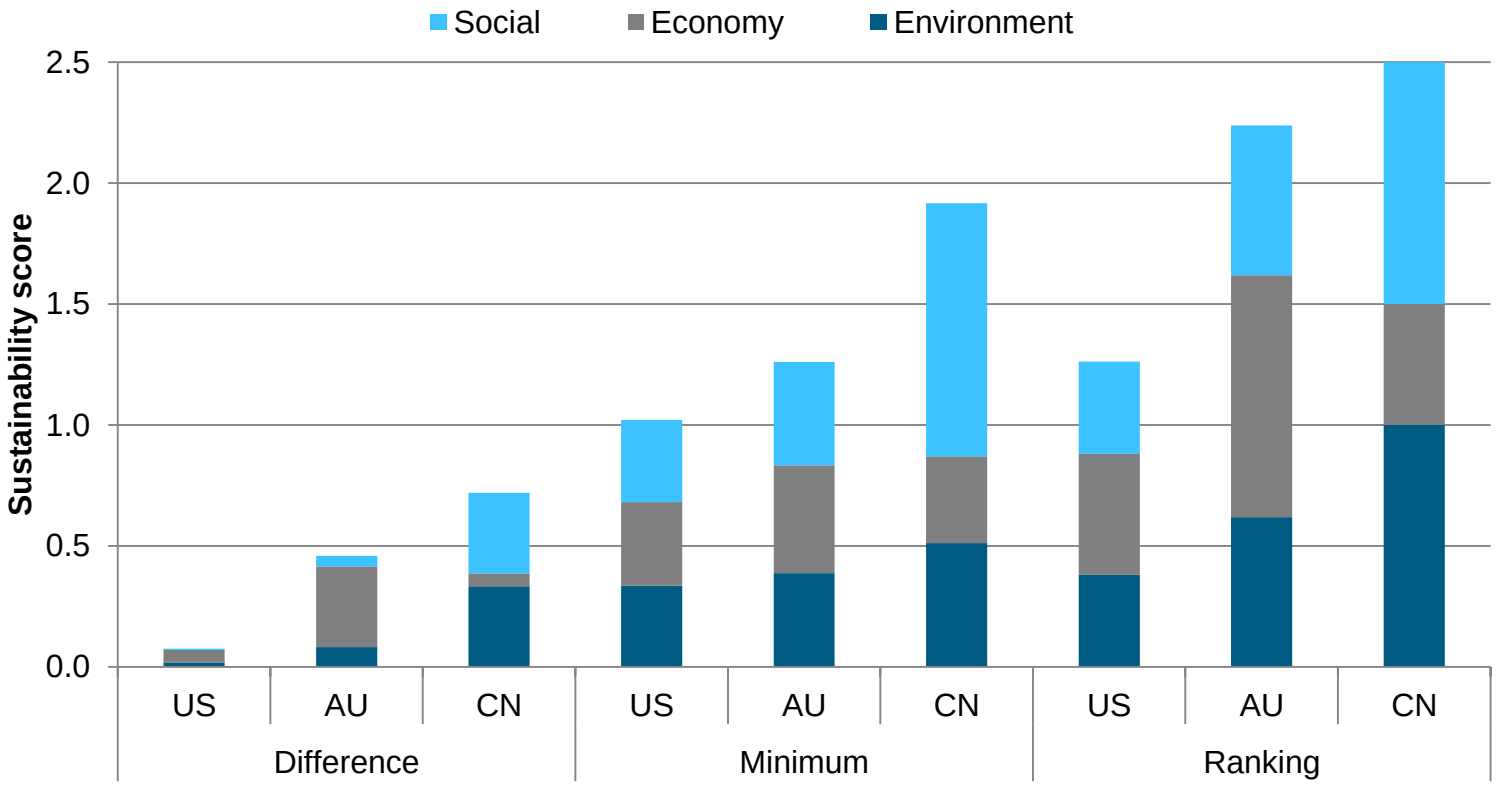
Multi-criteria decision-making

- Normalization
  - Difference/min-max $\widehat{x_{ij}} = \frac{x_{i,j} - x_{i,min}}{x_{i,max} - x_{i,min}}$
  - Minimum
  - Ranking
- Weighting
  - Equal weights per sustainability dimension + equal weights per indicator
- Aggregation
  - Weighted sum

Results MCDM



Results MCDM indifference threshold



Conclusions

- Chinese products reach highest environmental impacts mainly due to poor waste water and sludge treatment
- OPEX always significantly higher than CAPEX – OPEX strongly influenced by chemicals, waste treatment and energy
- Most influential social indicators are
  - Characterization of Heidelberg Barometer1
  - Characterization of CIRI Independent Judiciary
  - Risk that a country lacks or does not enforce the right of strike
- RE permanent magnets from China are least sustainable
- Different normalization methods can influence the overall result

Thank you for your attention!

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